P-23: Neutron Science and Technology

Sudbury Neutrino Observatory Experiment

T. J.Bowles [(505) 667-3937], S.Brice, E.I.Esch, M.M.Fowler, A.Goldschmidt, A.Hime, F.McGirt, P.Thornewell (P-23), J.B.Wilhelmy, J.M.Wouters (CST-11), collaborators from Lawrence Berkeley National Laboratory, Queen's University (Kingston, Ontario, Canada), Chalk River Laboratories (Ontario, Canada), Centre for Research in Particle Physics (Ottawa, Ontario, Canada), Carleton University (Ottawa, Ontario, Canada), University of Guelph, Laurentian University (Sudbury, Ontario, Canada), University of British Columbia (Vancouver, Canada), University of Pennsylvania, University of Washington, and Oxford University (United Kingdom)

In order to make a model-independent test of the origin of the solar-neutrino problem, we have joined the Sudbury Neutrino Observatory (SNO) experiment. The SNO detector (which will soon to be operational) is a water Cerenkov detector with 1,000 tonnes of heavy water contained in an acrylic vessel. The acrylic vessel is surrounded by another vessel with 8,000 tonnes of light (regular) water in which 9500 8-in. photomultipliers view the Cerenkov events in the heavy water. Solar neutrinos produced from the decay of ^{8}B in the sun may interact with the deuterium in the heavy water either to produce an electron (which is observed from its Cherenkov radiation) or to break up the deuteron into a proton and a neutron. The first (charged current) reaction can be initiated only by electron-type neutrinos, whereas the latter (neutral current) reaction can be produced by any of the three flavors of neutrinos (electron, muon, or tau). Our group at Los Alamos National Laboratory (LANL) originated and developed the use of extremely low background ^{3}He counters to be installed in the SNO detector as a means of detecting the neutrons produced by solar neutrinos. (As a spin-off, the semiconductor industry is very interested in using the very sensitive, low-background detectors to screen high-density microelectronics for trace radioactive contaminants that can cause computer errors by "flipping" bit patterns.) The SNO detector will carry out two model-independent tests of the origin of the solar-neutrino problem. In the first method, we will accurately measure the shape of the ^{8}B neutrino spectrum and see if the distortion characteristic of neutrino oscillations is occurring. In the second, we will observe if the rates of the charged and neutral current interactions are equal. If they differ, this would also indicate that neutrino oscillations are occurring.

GaAs Detector Development

T.J.Bowles [(505) 667-3937], S.Brice, A.Goldschmidt, A. Hime (P-23), M.Fowler, J.Wilhelmy (CST-11), collaborators from the Institute for Nuclear Research (Moscow, Russia), and Ioffe Institute of Physical Sciences

A GaAs detector can offer substantial advantages over other technologies in searches for weakly interacting massive-particle (WIMP) dark matter and high-resolution measurements of the solar-neutrino spectrum. GaAs offers the prospect of providing lower backgrounds than possible in other detectors along with a low energy threshold and very good energy resolution at room temperature. The physics that can be addressed is at the forefront of modern physics. In the short term, our efforts will be directed at searching for the cold dark matter that apparently makes up 90% of the mass in the universe. In the long term, it may prove feasible to address the question of neutrino mass using a large GaAs solar-neutrino detector. This could provide the possibility of making a very precise determination of the neutrino-oscillation parameters (if neutrino oscillations are shown to be the source of the solar-neutrino problem), a model-independent test for the existence of sterile neutrinos, and a model-independent measurement of the central temperature of the sun.

We have formed a collaboration with the Institute for Nuclear Research in Moscow to develop small GaAs detectors and to construct a prototype dark-matter detector. If successful, we then plan to propose a full-scale dark-matter detector that would be capable of covering most of the predicted range for the existence of WIMPs. This research would also allow us to determine the technical feasibility of pursuing a large-scale GaAs solar-neutrino detector.

EMIT

T. J. Bowles [(505) 667-3937] (P-23), G. L. Greene (LANSCE-DO), collaborators from the University of Michigan, National Institute of Standards and Technology (NIST), University of California at Berkeley, University of Washington, and Notre Dame University

The discovery of charge-parity violation by Cronin and Fitch, coupled with the CPT theorem (one of the basic tenets of modern physics), necessarily implies the existence of time violation. However, unlike parity violation, time-reversal invariance violation (TRIV) has been observed only in the kaon system, and presently several alternative theoretical explanations are possible. Untangling this interesting puzzle requires a variety of experiments that have unique sensitivities to the many models that predict possible TRIV effects.

Los Alamos initiated the EMIT ("TIME" reversed) collaboration to pursue a search for TRIV in the beta decay of the free neutron. A nonzero triple correlation between neutron spin, electron momentum, and proton recoil violates T symmetry. The experimental technique is to record the betas and proton recoils from the in-flight decay of polarized, cold neutrons. The TRIV signal consists of a nonvanishing difference when the neutron spin is flipped. A Monte Carlo study to model experimental sensitivity, verified by a test measurement, has revealed an optimized detector geometry seven times more sensitive than geometries employed in previous experiments. An octagonal detector geometry (4 proton- and 4 electron-detector assemblies) has been constructed, and we are now beginning to exploit this sensitivity and take data using the cold-neutron beam at the NIST reactor. We expect to improve the sensitivity of the previous measurements (which were at the 3×10^{-3} level) by an order of magnitude.

SAGE

T.J.Bowles [(505) 667-3937], J.S.Nico, W.A.Teasdale, D.L.Wark (P-23), collaborators from the Institute for Nuclear Research of the Russian Academy of Sciences, University of Washington, University of Pennsylvania, and Louisiana State University

The number and spectrum of neutrinos from the sun continues to challenge our understanding of solar physics and neutrino properties. Los Alamos has been the lead U.S. laboratory in the SAGE (Soviet-American gallium solar-neutrino experiment) collaboration since it began in 1985. SAGE is a radiochemical experiment located at the Baksan Neutrino Observatory in southern Russia.

Solar neutrinos produce ^{71}Ge atoms by inverse beta decay on ^{71}Ga. The ^{71}Ge atoms are chemically extracted from the 60 tons of metallic liquid gallium, and their decay is measured in miniature ultralow-background proportional counters. SAGE is sensitive to all of the fusion reactions occurring in the sun. Beginning in 1990, we have carried out measurements of the flux of solar neutrinos and have found that the flux of neutrinos detected is about half of that predicted by the Standard Solar Model. We have also confirmed the correct overall operation of the experiment using an intense (0.5 MCi) ^{51}Cr artificial neutrino source. Combined with results from other solar-neutrino experiments that measure only the higher-energy solar neutrinos produced from ^{7}Be and ^{8}B reactions in the sun, it appears that the most plausible explanation of the observed deficit is neutrino oscillations. If this proves to be true, it will be the first evidence for physics beyond the Standard Electroweak Model, as predicted by the Grand Unified Field Theories.

Ultracold Neutrons

T.J.Bowles [(505) 667-3937], S.J.Seestrom, R.Hill (P-23), C.Morris, G. Hogan (P-25), T.Brun (LANSCE), collaborators from the University of Rhode Island, University of California at Berkeley, and Petersburg Nuclear Physics Institute

Ultracold neutrons (UCNs) are neutrons whose wavelengths are sufficiently long that they can undergo total internal reflection from a variety of materials. This makes it possible to confine UCNs in a bottle for more than 100 seconds, providing a compact source for use in fundamental physics research.

At LANSCE, ultracold neutrons were first produced in 1996 by Bragg-scattering cold neutrons (having a velocity of 400 m/s) from a moving mica-crystal package so that the cold neutrons were Doppler shifted into the ultracold regime (<7 m/s). We are continuing to develop this source with improved diagnostics, a mica-crystal package with higher reflectivity, and better control of the matching of the source to the MLNSC cold moderator. We are also developing the use of cryogenic moderators for UCN production at the proposed Long-Pulse Spallation Source. This source promises densities 100–1000 times higher than presently available. Such an intense source of UCNs may make it possible to pursue materials-science applications with UCNs.

A fundamental-physics research program with UCNs is now being started with plans for measurement of angular correlations in polarized UCN beta decay and the electric dipole moment of the neutron. These experiments aim at detecting physics beyond the Standard Model of strong and electroweak interactions.

Neutron Total Cross Sections

F.S.Dietrich (Lawrence Livermore National Laboratory), W.P.Abfalterer [(505) 667-3632], R.C.Haight (P-23), R.W.Finlay (Ohio University)

This joint project of Lawrence Livermore National Laboratory (LLNL), Ohio University, and LANL is making precise measurements of the neutron total cross sections over a wide neutron energy range for a comprehensive set of materials for the Accelerator Production of Tritium (APT) program. These data are necessary in the calculations of neutron transport in APT systems, and they are essential input to model calculations of neutron scattering and reactions. In 1996, we investigated over 30 samples in the energy range 4–550 MeV and obtained data accurate to approximately 1%. The WNR fast-neutron spallation source at LANSCE is ideal for this work. We are continuing this work in 1997 with additional materials, including isotopes of tungsten and iron.

Nuclear Level Densities

R.C.Haight [(505) 667-2829], F.B.Bateman (P-23), S.M.Grimes (Ohio University), H.Vonach (University of Vienna)

At low excitation energies, a given nucleus has a sequence of energy levels that can be described by their quantum numbers and spectroscopic properties. At higher excitation, the number of levels rises very quickly, so that the properties of the individual levels cannot be determined individually but must be understood as statistical averages such as the "nuclear level density." It is generally believed that there is a transition from the ordered set of states at low energy to a Fermi gas (a gas-like collection of protons and neutrons) at much higher energies. The characterization of the transition between the two regimes is the subject of many theories. We test these models by measuring, with the WNR/LANSCE spallation neutron source, neutron-induced, charged-particle-producing reactions over the range from threshold to 50 MeV. Three independent approaches are possible with these reactions: the shape of the emission (evaporation) spectra gives information on the nuclear level density in the residual nucleus; the cross section as a function of energy indicates level densities for excited states in the target nucleus; and very-high-resolution measurements with respect to incident neutron energy reflect overlapping states in the compound nucleus. The quantification of nuclear level densities is essential for nuclear-reaction models of reactions that cannot be measured, such as reactions on unstable species that are formed in stellar nucleosynthesis and in the explosion of nuclear weapons.

Milagro Gamma-Ray Observatory at Fenton Hill

T. J. Haines [(505) 667-3638], R. Miller, C. Sinnis (P-23), C. M. Hoffman (P-DO), G. Gisler (NIS-2), collaborators from the University Autonoma de Barcelona, University of California at Irvine, University of California at Riverside, University of California at Santa Barbara, University of California at Santa Cruz, University of Maryland, George Mason University, University of New Hampshire, New York University, and University of Utah

The Milagro Gamma-Ray Observatory at Fenton Hill in the Jemez Mountains uses hundreds of sensitive, light-detecting photomultiplier tubes submerged in a five-million-gallon artificial pond to record signals from high-energy cosmic emissions. Milagro—the Spanish word for "miracle"—is a collaboration involving researchers from LANL; University of California (UC) campuses at Irvine, Riverside, and Santa Cruz; the University of Maryland; George Mason University; the University of New Hampshire; and New York University. The $2.5-million project is funded by the National Science Foundation, DOE, and UC. The 25-ft-deep pond was emptied and covered with durable, waterproof plastic. The water in the pond is circulated, filtered, and treated to maintain its clarity in a support building next to the pond, which also holds the computers and electronics that process the signals recorded by Milagro. The pond was refilled with water after the first 225 light detectors in the bottom array were installed. In the summer of 1998, project members will drain the pond and expand the array to its full size.

Milagro is sensitive to a range of gamma rays, high-energy photons with energies above 500 GeV. These gamma rays, generated by black holes, active galaxies, supernovae, or “gamma-ray bursters,” strike air molecules in the upper atmosphere before they reach Earth. These initial collisions produce showers of subatomic particles and lower-energy photons that avalanche groundward in a cone. Each air shower either dissipates in the atmosphere or, at high elevations, intercepts the ground. Milagro’s pool acts as a camera larger than a football field and stares at the sky around the clock. A light-tight cover on the pool keeps the inside of the observatory absolutely dark but is easily penetrated by the energetic particles in the air shower. When a gamma-ray-generated air shower strikes the pool, electrons and positrons in the shower create Cerenkov radiation as they move through the water. Milagro’s light detectors sense this light and record information for reconstructing the point on the sky from which the original gamma ray came. Milagro observes hundreds of events each second. Computers automatically sift the arriving data, discarding the many background events generated by cosmic rays and recording the gamma-ray signals.

Gamma-ray bursters, which flash briefly into view and then disappear, have puzzled astronomers since they were discovered by Los Alamos scientists in the 1960s. Currently, astronomers are debating whether gamma-ray bursters originate in our own galaxy or reach us from the most remote reaches of the universe. The latter explanation would require exotic new physics to explain such powerful bursts of energy. Milagro can help to answer the question of whether or not the gamma-ray bursters are located at cosmological distances; researchers are eager to combine its data with those from the Gamma Ray Observer satellite, which observes less-energetic gamma rays from its vantage point in space. Milagro builds on the success of the CYGNUS experiment, which ran at Los Alamos for 10 years. CYGNUS, begun by Darragh Nagle of Los Alamos and collaborators at the University of Maryland, used only scintillation detectors and was sensitive only to gamma rays at the upper end of Milagro’s range of detection. Data from the CYGNUS experiment have to date produced 10 doctoral dissertations. Milagro’s flood of data will support many more graduate students studying high-energy physics and astrophysics; the project currently employs 7 graduate students, including 4 doctoral candidates.

Fundamental Symmetry Measurements with Trapped Atoms

A.Hime [(505) 667-0191], T.J.Bowles, S.J.Brice, A.Goldschmidt, R.Guckert (P-23), E. I.Esch, D.Tupa (P-25), M.M.Fowler, D.J.Vieira, J.B.Wilhelmy, X.Zhao (CST-11), C.Weiman (NIST)

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments has arisen that would exploit point-like, massless samples of essentially fully polarized nuclei. At Los Alamos we are pursuing a measurement of the beta-spin correlation function in the beta decay of ^{82}Rb confined to a time orbiting potential (TOP) magnetic trap as a means to probe the origin of parity violation in the weak interaction. A new generation of atomic-parity nonconservation experiments that test the neutral current part of the weak interaction is also envisioned, wherein measurements with a series of radioactive isotopes of cesium and/or francium could eliminate atomic structure uncertainties that presently limit the ultimate precision of such experiments.

Our near-term goals are to demonstrate the high-efficiency optical trapping of rubidium and cesium radioisotopes, to polarize and transfer these cold atoms to a pure magnetic trap that confines only one polarized state, and then to measure the beta-asymmetry using a symmetric array of beta-telescopes surrounding the trap. Initial trapping and cooling of rubidium and cesium isotopes have been carried out, and we are now working to complete the design of the transfer and the second magnetic trap, where ^{82}Rb atoms will be polarized and placed in a magnetic TOP trap for high-precision beta-asymmetry measurements. Our initial studies will concentrate on the pure Gamow-Teller transition in ^{82}Rb; our goal is to measure the parity-violating beta-spin asymmetry correlation with a precision one order of magnitude greater than any previous experiment.

Quantum Cryptography for Secure Communications to Low-Earth-Orbit Satellites

R.J.Hughes [(505) 667-3876], W.T.Buttler, G.G.Luther, G.L.Morgan, C.G.Peterson, C.Simmons (P-23), J.E.Nordholt (NIS-1)

Cryptanalysis techniques and algorithms are advancing rapidly and by the start of the twenty-first century will necessitate the development and use of new encryption technologies to ensure secure communications to satellites. The aim of our project is to develop quantum cryptography so that it may provide absolutely secure encryption of communications to low-earth-orbiting satellites. We will develop and demonstrate the cryptographic technology to a stage where it can be feasibly incorporated into new satellites. During the past year, we have designed, constructed, and tested a quantum-cryptography system that creates and transmits—using single-photon transmissions—cryptographic random numbers between sending and receiving instruments separated by more than 200 m within our laboratory. The system is based on the propagation and detection of nonorthogonal polarization states of single photons in free space at a wavelength (771 nm) for which the atmosphere has a very low attenuation.

Quantum Computation Using Cold, Trapped Ions

R.J.Hughes [(505) 667-3876], M.H.Holzscheiter, P.G.Kwiat, S. K. Lamoreaux, C.G.Peterson, C.Simmons (P-23), M.Schauer (P-24), M.Gulley, V.Sandberg, D.Tupa (P-25)

Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows computing with quantum-mechanical superpositions of many numbers at once. In a quantum computer, binary numbers will be represented by quantum-mechanical states (“qubits”). We are developing a quantum-computational device in which the qubits will be two electronic states of calcium ions that have been cooled with a laser to rest in an ion trap. We will then perform quantum logical operations with a laser beam that is resonant with the qubit transition frequency and is directed at individual ions. We have recently succeeded in trapping and imaging a cloud of calcium ions using two titanium-sapphire lasers: one, frequency doubled to 397 nm; the other at 866 nm.

Quantum Cryptographic Key Distribution over Optical Fibers

R.J.Hughes [(505) 667-3876], G.G.Luther, G.L.Morgan, C.G.Peterson, C.Simmons (P-23)

The secure distribution of secret random-bit sequences, known as “key” material, is an essential precursor to the use of that key material for the encryption and decryption of confidential communications. Quantum cryptography is an emerging technology for secure key distribution with single-photon transmissions. Heisenberg’s uncertainty principle ensures that an adversary can neither successfully tap the key transmissions nor evade detection, because eavesdropping raises the key error rate above a threshold value. We are performing quantum cryptography over 48 km of underground optical fiber using nonorthogonal single-photon interference states to generate shared key material. Key material is built up by transmitting a single photon per bit of an initial secret random sequence. A quantum-mechanically random subset of this sequence is identified and becomes the key material after a data-reconciliation stage with the sender. The nonorthogonal nature of the quantum states ensures that an eavesdropper cannot identify the bit values in the key sequence. Our experiment demonstrates that secure, real-time key generation over “open,” multikilometer node-to-node, optical-fiber communications links is possible.

Diode Laser Development for Quantum Computation

R.J.Hughes [(505) 667-3876], P.G.Kwiat, C.G.Peterson (P-23), J.Gomez, V.Sandberg, C.Simmons, D.Tupa (P-25)

Titanium-sapphire lasers are a proven technology for our quantum-computation application, but they are expensive, require a laser expert, use over 40 kW of power, and fill an entire laser table. The objective of this project is to develop diode lasers for this application because diode lasers are easy to use, low in cost, and compact. This year, we have developed diode lasers at the 866-nm and 794-nm wavelengths that are required for cooling calcium ions, and in the next few months, we will double the frequency of the 794-nm light to obtain 397-nm light. We have assembled external-cavity diode-laser systems and, with a prototype, demonstrated locking to an existing frequency standard. We have developed frequency-offset techniques using modulators and/or ultrastable cavities to reference the 866- and 397-nm wavelengths to stable atomic lines. Typically, the wavelength of the light emitted by the laser must be controlled with respect to a reference wavelength, which is near the desired wavelength. For our diode lasers, we can reference light wavelengths to an absolute atomic standard or to a very stable optical cavity that resonates at a very well defined frequency.

"Interaction-Free" Measurements

P.Kwiat [(505) 667-6173], A.White, J.Mitchell (P-23), collaborators from the University of Innsbruck (Austria)

Using the complementary wave- and particle-like nature of light, it is possible to determine the presence of an object without any photons being absorbed or scattered by it. The maximum efficiency of the simplest schemes (wherein the object, if placed in one arm of an interferometer, prevents interference) is only 50%. However, by incorporating a repeated interrogation scheme—an application of the Quantum Zeno effect—one can, in principle, achieve efficiencies arbitrarily close to 100%, with an arbitrarily small chance that any photons are absorbed. So far, an 85%-interaction-free measurement has been achieved (in collaboration with researchers at the University of Innsbruck), and this is the current world record. A fast switching system that should allow efficiencies in excess of 95% is currently under development. Also, we have begun investigating the practical implementation of interaction-free imaging, in which these techniques are used to obtain a pixelated image of an object, again with the goal of negligible absorption or scattering. To date, a resolution of less than 10 μm has been achieved, and we hope to improve this even further. Finally, we are beginning research on coupling our measurement system to a quantum object in a superposition state. This would allow the production of macroscopic entangled states of light and Schrödinger-cat states.

Development of a Cold-Neutron Radiography Capability at the Manuel Lujan Neutron Scattering Center (MLNSC)

T.E.McDonald, Jr.[(505) 667-7294]) (P-23), T.N.Claytor, M.J.Schwab(ESA-MT), E.H.Farnum (MST-4), G.L.Greene (LANSCE-DO), A. Michaudon (LANSCE-3)

Neutron radiography is an attractive technique for nondestructive testing and evaluation due to the strong variation of neutron cross sections from element to element. Cold-neutron radiography (CNR), which uses neutron energies in the millielectronvolt (meV) regime, has been employed for the most part with reactors in which a steady-state source of cold neutrons can be obtained. Spatial resolutions of a few tens of microns can be obtained in radiographs from such sources. An important behavior of the cross sections of crystalline materials for cold neutrons is that below an energy of a few meV (the exact energy depends on the material), there is an abrupt drop in the cross section when the wavelength reaches twice the largest d-spacing of the material. The energy at which this abrupt drop occurs is referred to as the Bragg cutoff. This behavior is generally not exploited in a reactor environment because the steady-state nature of the neutron source does not facilitate the separation of neutrons of different energies. However, a pulsed neutron source using a time-of-flight capability can easily differentiate neutron energies and thus has the capability to obtain radiography at various neutron energies. By recording image data at different times during a neutron pulse, it is possible to obtain neutron images below and above the abrupt drop (or threshold) in the cross section for a given component of the sample.

We recently demonstrated this phenomenon at the MLNSC on Flight Path 11a. A beam guide was installed to achieve a flight path of approximately 19 m. A lithium zinc sulfide scintillator was used as a neutron-to-light converter, and a set of mirrors and lenses relayed the image from the scintillator to a gated image intensifier, the output of which was recorded by a cooled charge-coupled device (CCD) camera. We have demonstrated the Bragg cutoff at 6 meV on a block of beryllium that is approximately 73 mm thick. Imaging at energies above about 7 meV shows the beryllium to be dark, and items being shadowed by the beryllium cannot be seen. However, imaging at energies below approximately 5 meV shows the beryllium to be almost clear, and items previously shadowed by the beryllium can be clearly seen. These images are our first proof-of-concept experiment, and we expect to achieve increased resolution and image quality in subsequent work.

Neutron-Based Land-Mine Detection System Development

T.E.McDonald, Jr.[(505) 667-7294] (P-23), H.A.Davis (P-24),
R.A.Nebel (T-15), M.M.Pickrell (NIS-5)

Determining the location of land mines is important both militarily and in peace time. Even in today's absence of large conflicts, more than 26,000 people are killed or wounded yearly by land mines that were deployed previously. The goal of this project is to examine the feasibility of developing a buried-land-mine detection system using the detection and analysis of prompt gamma rays that are induced by neutron interrogation. This technique is a mature concept and has been used in a variety of explosives-detection applications. However, it has not successfully been applied to the buried-mine detection problem because of lack of both a suitable neutron source (that is, one having sufficient intensity) and a detection system having a sufficiently high signal-to-noise ratio. The basic concept is to interrogate a suspected area with neutrons. The explosives in any mines that may be present would have an elevated presence of nitrogen, whereas the surrounding earth generally would have little or no nitrogen. Some of the neutrons would react with the nitrogen in the explosive, and gamma rays that have specific and unique energies would be emitted as a result of the reaction. Most previous attempts to use this neutron-based (NB) technology for mine detection have relied on spontaneous fission sources, which can be used only at low intensity, in the range of 10^6–10^7 neutrons per second (n/s), together with heavy shielding, because of personnel safety considerations. A system using such low-intensity sources is slow (requiring several minutes) and requires close proximity (within a few centimeters) to the explosive being detected. Most studies indicate that a source strength in the range of 10^9–10^{11} n/s would be necessary to achieve a relatively high signal-to-noise ratio in an interrogation time of a few seconds. In this project, we consider two alternative neutron sources that have the potential of producing neutron fluxes in the neighborhood of 10^{11} n/s: the Intense Ion-Beam Source and the Inertial Electrostatic-Confinement Source. The advantage of these sources is that they can be turned off when not in use and can be operated over a wide range, from steady state to pulsed. We also review alternative detection techniques and have carried out preliminary measurements using mock high-explosive (HE) material.

Advanced Technology Imaging Sensor Development (Fast CCD Sensors)

T.E.McDonald, Jr. [(505) 667-7294], G.G.Yates, R.A.Gallegos, N.S.P.King (P-23), B.T.Turko (Lawrence Berkeley Laboratory), F.J.Zutavern (Sandia National Laboratories), M.C.Thomas (Bechtel Nevada)

The goal of the Advanced Technology Imaging Sensor Development (Fast CCD Sensors) project is to develop an advanced, gated, intensified imaging system for use over a broad range of applications in the Department of Defense (DoD) and Department of Energy (DOE). Our focus is on increased frame rate, extended spectral range sensitivity into the near infrared (including the "eye-safe" spectrum in the neighborhood of 1.54 μm), reduced gate width, increased resolution, and increased quantum efficiency. Such an advanced imager would be used in the DoD in lidar; range gating; imaging through scattering media such as fog, clouds, and turbid water; long-distance target acquisition and ranging; underwater imaging; and laser detection and ranging (LADAR) imaging, including eye-safe LADAR. Applications in the DOE include shock-wave-breakout characterization, neutron and proton radiography of dynamic systems, imaging of high-speed assembly and associated reactions, and diagnostics of accelerator beam pulses. The high-speed imaging technology developed by Los Alamos and the other DOE national laboratories for use in the underground testing program at the Nevada Test Site (NTS) serves as the technology foundation for this project. Starting with this base, we are advancing the technology along several fronts. We are designing a high-speed camera around a new 512 × 512 pixel, 16-port CCD. The camera is designed to operate continuously at up to 4000 frames per second. We are working on the design of microchannel plate intensifier configurations that will gate in the few-hundred-picosecond regime, and we are working with manufacturers on the fabrication of such intensifiers. We are also working with intensifier manufacturers on extending the sensitivity of the photocathode to cover the near infrared up to the eye-safe spectrum range. In addition, we are pursuing a quantum improvement in intensifier technology by using a back-thinned, electron-bombarded CCD (EBCCD) that will be placed directly in the intensifier envelope and replace the microchannel plate, phosphor, and intensifier-camera coupling. If the EBCCD development is successful, we expect close to an order-of-magnitude improvement in sensitivity and resolution.

Basic Physics with Spallation-Neutron Sources

A.Michaudon [(505) 665-2883] (LANSCE-3)

Progress in basic physics with neutrons strongly depends on the availability of intense neutron sources. High-flux reactors are at the limit of their technical possibilities, with no substantial progress in performance in the last twenty years. Spallation-neutron sources (SNSs) that use intense proton beams (of about 1 GeV) already have demonstrated both interesting capabilities that complement those of reactors and great potential for future development. Although neutron sources are mainly used for condensed-matter studies, they also present attractive possibilities for studies in other fields, including nuclear physics, fundamental physics, and particle physics.

The interest and future potential of SNSs, which can produce neutrons with an energy range spanning 16 orders of magnitude, and their possible use in scientific disciplines outside that of condensed matter have been reviewed in detail in a major 3-volume report[1] written by more than 30 scientists from inside and outside LANL. This report forms a comprehensive base in support of the launching of LANSCE as a truly multidisciplinary national user facility.

1. "Basic Physics with Spallation-Neutron Sources," A. Michaudon, Ed., Los Alamos National Laboratory document LA-UR-94-1320 (1994).

Use of Ultracold Neutrons for Condensed-Matter Studies

A. Michaudon [(505) 665-2883] (LANSCE-3)

Ultracold neutrons (UCNs) have played a very important role in fundamental-physics research but can also be used in condensed-matter studies. Because of their small penetration depth into matter, UCNs are well suited for surface studies. High-resolution UCN spectrometers can also be built, using gravity as a strongly dispersive medium for low-energy neutrons. With such excellent resolution, UCN quasielastic scattering can give insight into slow dynamics over long distances in macromolecules such as polymers or biopolymers. All these studies were recently reconsidered with the possible advent of new, more-intense UCN sources, which are now envisaged. This reassessment, now available as a Los Alamos report, includes a broad review of UCN properties (including their reflectivity by different types of samples), UCN spectrometers and their comparison with other high-resolution instruments, experimental results obtained with all these instruments, and neutron microscopes.

Infrared Pyrometry for Temperature Measurements of Shocked Surfaces

A.W.Obst [(505) 667-1330], N.S.P.King, M.L.Stelts (P-23), collaborators from Bechtel Nevada and DOE Los Alamos Area Office

Measurements of the time-dependent absolute temperature of surfaces shocked by high explosives (HE) provide valuable constraints on the equation of state of materials and on the state of ejecta from those shocked surfaces. A pyrometer system has been designed and built for studying these temperatures, which typically lie in the range 0.04–0.2 eV, corresponding to shock heating of surfaces to temperatures from about 400 K to about 2000 K. These temperatures are equivalent to infrared (IR) wavelengths in the range of 1 to 10 μm. Blackbody IR spot pyrometry, utilizing the color ratio technique, permits a measurement of these surface temperatures. An a priori knowledge of the behavior of the surface emissivity with wavelength is required, but the absolute values of the emissivity are not. This detector system will be applied to experiments in the above-ground experiments (AGEX) program.

The detector system uses IR lenses to image a spot (whose diameter is determined by the optics) onto a mixing rod. The mixing rod allows spatially homogenized samples of the IR emission to be transferred to three 3-m-long IR fibers. The other ends of the fibers go to a detector box, which can be protected from the HE shock. The IR radiation from each of the three fibers is focused through a doublet lens system onto quad metal (HgCdZnTe) IR detectors. Filters are placed between the doublets to transmit IR radiation only from moderately narrow bands. The three bands are centered about 3, 6, and 8 μm to optimize the color ratios for the temperature range of interest. The system is being characterized and will be tested on flyer plate configurations driving polished copper plates, for which the temperature has been well characterized.

Ejecta Measurements Using In-Line Fraunhofer Holography

D.S.Sorenson [(505) 665-2860], N.S.P.King, A.Obst, M.Stelts, N.Gray, V.Holmes, S.Jarimillo (P-23), collaborators from Bechtel Nevada

When a shock wave interacts at the interface between a solid (or liquid) and a gas, pieces of the material can be emitted into the gas region. This material can range in size from submicron to hundreds of microns and is referred to as ejecta. Ejecta can occur in a nuclear weapon when a shock wave interacts at such an interface. The amount, size, and velocity of ejecta will depend on material properties such as grain size, surface finish, and the state of the shock wave in the material. In order to characterize ejecta, P-23 has played a major role in developing an in-line Fraunhofer holography technique to make measurements of ejecta in a dynamic system. This diagnostic has been developed and implemented on numerous experiments based at the Pegasus II Pulsed-Power Facility and is currently being developed for HE experiments. At Pegasus, an aluminum cylinder is imploded and then impacts a smaller-diameter target cylinder, which sets up a shock wave in the target. When the shock wave interacts at the target/vacuum interface, ejecta are emitted. To make the ejecta holographic measurement, a laser pulse is transported through the ejecta, where part of the laser light scatters and part is unscattered. These two beams interfere at the film plane where the hologram is formed. The hologram contains information about particles ranging in size from a few microns to a hundred microns in diameter over a volume of 1 cm^3. Ejecta data have been obtained for both aluminum and tin targets over a range of surface finishes and shock strengths.

X-Ray Imaging Experiments Using Pulsed-Power and High-Explosive Facilities

D.S.Sorenson [(505) 665-2860], N.S.P.King, A.Obst, M.Stelts, N.Gray, V.Holmes, S.Jarimillo (P-23), D.Morgan, D.Platts (P-22), collaborators from Bechtel Nevada

Many weapons-physics issues deal with instabilities and shock waves interacting in materials and gases. In order to investigate these issues associated with dynamic systems, groups P-23 and P-22 are developing a spatially resolved, time-dependent x-ray imaging system. Providing time-dependent information is critical in understanding the physics involved and in comparing experimental data with predictions given by the hydrodynamic weapon codes. The system makes use of 600-keV x-ray sources developed in P-22, which provide roughly 100 mrad at a distance of one foot in a 10-ns full-width-at-half-maximum (FWHM) pulse. P-23 has developed scintillator packages for forming the image, an optical transfer system for relaying the image, and gated-intensifier camera systems for recording the image. Depending on the type of experiment, the scintillator type and thickness are optimized to maximize image contrast. The optical-transfer system is designed to relay the image far enough from the experiment that the camera systems are protected, while still providing high resolution and good light collection. Many experiments have been successfully completed at the Pegasus II Pulsed-Power Facility, where images at two different times were obtained. For the Icebound and local HE experiments, a time-dependent x-ray imaging system is being developed. With this system we are making images over an 18-mm-diameter area that allow us to measure ejecta mass with an accuracy of 10%.

P-23 Weapons-Physics Experimental Team

M.L.Stelts [(505) 667-1507], K.R.Alrick, N.T.Gray, V.T.Holmes, P.Liu, A.W.Obst, D.S.Sorenson (P-23), collaborators from Bechtel Nevada

This team performs experiments that expand our understanding of the physical processes that take place in the detonation of nuclear devices. Some issues that are being studied include the development of instabilities that form in imploding systems, the formation of ejecta from shocked surfaces, interaction of shock waves with materials, and equation-of-state (EOS) measurements in materials and pressure regimes of interest to weapons physics. The experiments are performed using liners imploded with pulsed power at the Pegasus II facility and on explosively driven systems both at LANL and in the U1a facility at the Nevada Test Site (NTS).

We apply a variety of diagnostics to measure the physical phenomena that occur in these experiments. Holograms, taken with a pulsed laser, measure the distribution of particle size in ejecta. We have developed a system to take a sequence of gated x-ray images to provide information on the evolution of instabilities and the mass distributions in surface ejecta. Visible imaging experiments, which either use framing cameras to capture the emitted light from shocks or use lasers or argon candles to backlight the experiments, provide information on the evolution of the phenomena being investigated. We are developing pyrometers to measure time-dependent temperatures and IR imaging techniques to study spatial distributions of temperatures for shocked systems. Various techniques, including the use of streak cameras, are employed to measure shock arrival times in EOS experiments.

P-23 NTS Prompt Diagnostic Archival Team

M.L.Stelts [(505) 667-1507], P.Liu, K.B.Morley (P-23), collaborators from Sumner Associates and Bechtel Nevada

The laboratory is now required to certify our nuclear-weapons stockpile without being able to test the weapons. This will require the development of better physics models and better computer codes that, ultimately, should be able to compute the performance of the weapons, including effects of aging, defects, and remanufacture. To have confidence in the ability of these codes to provide realistic predictions, we must be able to use them to successfully model the performance of devices tested at NTS. Thus, the NTS data will be a crucial link in attaining this goal.

P-23 and its predecessor groups have been responsible for experiments that involve precision neutron output measurements from these devices (NUEX and THREX) and for the imaging of sources of radiation in the devices (PINEX), as well as many other experiments that have been performed to investigate weapons-physics issues. The responsibility of P-23 is two-fold. We are documenting the experimental techniques that were used in the NTS shots so that future users of the NTS data will understand how an experiment is designed, what information can be derived on the weapons-physics issues, and how to field the experiment if we are required to return to testing. We are also systematically saving the data, frequently having to reanalyze experiments, and providing the necessary additional information that will allow comparison of the experimental results with the calculations of device performance. These data are being electronically archived on the P-23 classified computer system in a form that facilitates access and use by other experimentalists, weapon designers, and code developers. To aid in this process, we have installed a World Wide Web–type page on our classified network (behind a firewall computer that limits access to those with a "need to know") to allow easier access to the data through a web browser.

The task of saving and documenting the data taken over decades of testing is formidable. It is necessary to recover data not only on stockpile systems, but on events designed to investigate weapons-physics issues and on those interesting failures, where the results were not what were anticipated.

Neutron Measurements to Support the Optimization of Treatment of Cancer Patients with Fast Neutrons

J. L. Ullmann [(505) 667-2517], R. C. Haight (P-23)

Over 15,000 people with cancer have received radiation treatment with fast neutrons. This clinical experience has shown that 10%–15% of all cancer patients would benefit from this neutron therapy. Accurate dosimetry depends on the knowledge of neutron interactions with elements of tissue such as carbon, nitrogen, and oxygen. In particular, neutron reactions that produce charged particles are of interest because these reactions deposit energy, and hence radiation dose, locally at the point of the interaction. Although there have been measurements in the energy range of importance, from 20 to above 70 MeV, the data base is sparse (we have measurements at only a few selected energies), and there are significant discrepancies among literature values. We are beginning a program to supply accurate data on neutron reactions that produce protons, deuterons, tritons, ^{3}He, and ^{4}He from 0–150 MeV, thereby covering the full range used in neutron therapy. The WNR/LANSCE neutron source covers this range continuously, and the specific neutron energy for a particular reaction can be determined by time-of-flight techniques. Applications of these data extend also to radiation protection at high-energy and medium-energy accelerators and to radiation effects from neutrons produced by cosmic rays.

Molten-Metal-Target Test Loop

S.A.Wender [(505) 667-1344] (LANSCE-3), F.Venneri, N.Li, M.A.Williamson, B.E.Newnam, G.D.Doolen (LANSCE/ADTT)

The development of molten heavy-metal-target technology for spallation neutron sources has recently become recognized as an important objective for several programs at Los Alamos. It is generally believed that the only way to take advantage of the accelerator-beam power levels now possible for compact neutron-spallation targets is to use molten metal as the target material. Molten-metal targets are called for in the National Spallation Neutron Source (NSNS) being designed by Oak Ridge National Laboratory, the European Spallation Source (ESS), and the SINQ project at the Paul Scherrer Institute (PSI). The accelerator-driven transmutation technology (ADTT) program at Los Alamos is proposing systems that depend heavily on molten lead or lead-bismuth eutectic (LBE) fluids for neutron production and for cooling. In addition, molten lead or LBE targets have been suggested as advanced concepts for use in the accelerator production of tritium (APT).

As a first step toward developing this technology at Los Alamos, we are constructing a simple LBE test loop. This test loop will allow us to address many issues, such as material compatibility and corrosion, and to gain experience with LBE. We will be working in close collaboration with scientists from the Institute of Physics and Power Engineering at Obninsk, Russia, who have considerable experience with LBE from their naval propulsion program. We expect the loop to be operational in late 1997.